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Weather Analysis Programs Using
HP-41CV

.by

Carlyle H. Wash

Laura A. Spray

November 1984

Technical Report Period: October 1983 – September 1984

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NAVAL POSTGRADUATE SCHOOL
Monterey, California
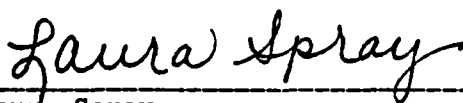
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Superintendent   Provost

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Dean of Science and Engineering

Errata List for Weather Analysis Programs
Using the HP-41CV (NPS-63-84-008)

1.   Page 1, Paragraph 3; Line 2 should read
      forecast from a set ......

2.   Page 11, Paragraph 1; Line 4 should read
      Renard's (1972) nomogram method ......

3.   Page 22, Paragraph 1; Line 7 should be
      $T_{amb} > T_{crit}$ rather than $T_{amb} < T_{crit}$ meaning 100% relative humidity.

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Accession For

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Justification

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Availability Codes

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Dist      Special

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gradient wind	HP-41

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Several synoptic problems, previously solved by graphical overlays, can be solved with a programmable calculator. The HP-41CV hand-held calculator is used to determine surface winds, the probability of average rainfall for a regional area (Monterey, California), contrail formation, and the lifting condensation level from surface data.

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ABSTRACT

Several synoptic problems, previously solved by graphical overlays, can be solved with a programmable calculator. The HP-41CV hand-held calculator is used to determine surface winds, the probability of average rainfall for a regional area (Monterey, California), contrail formation, and the lifting condensation level from surface data.

I. Introduction

This report describes four programs that use the HP-41CV calculator's programming capability in dealing with interesting meteorological problems, including determining surface winds, the probability of average rainfall for a regional area (Monterey, California), contrail formation and the lifting condensation level from surface data.

The programs were prepared to use the hand-held calculator in solving synoptic problems. The first problem is the estimation of surface wind at a point from a regional sea-level pressure analysis or forecast. This problem arose in the synoptic laboratory where wind forecasts were prepared with numerical weather prediction guidance (facsimile sea-level pressure maps). The immediate solution is a geostrophic wind scale applied to the facsimile chart. The HP program provides an alternative solution. The program calculates the geostrophic and gradient wind, as well as the estimated surface wind, using Ekman boundary layer assumptions, by simply entering latitudes, longitudes and pressure readings from a sea-level pressure chart.

The second problem involves preparing a statistical precipitation forecast for a set of graphical tables. Using a tutorial program in a hand-held calculator, the need for the graphical tables is eliminated. The program determines the probability of average rainfall over the Monterey, California area for the period 0800 PST forecast day to 0800 PST of the following day, for the wet-season months, November through April. This procedure is based on the Renard (1972) graphical objective technique for forecasting 24-h rainfall at Monterey, California. From the data entries of 500 mb heights used to calculate geostrophic relative vorticity at Monterey and a point $8°$ latitude upstream from Monterey, as well as sea-level pressure data, the program uses a series of pre-established data tables to arrive at a probability of 24-h rainfall for Monterey, California.

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The third problem involves forecasting contrails from upper-level sounding data. It was desired to have the HP make the decision from input sounding data as an alternative to plotting the entire sounding and using a graphical overlay. This program determines contrail formation at a given pressure level based on the curves found in the Contrails Forecasting Manual of Chief of Naval Operations (1964). A least squares approximation was made to the curves involving an expression for critical temperature which is a function of temperature, pressure and relative humidity. If the relative humidity is estimated (dew-point temperature is unknown), there is a series of criteria to determine whether or not contrails will occur.

The final problem is to determine the lifting condensation level (LCL) without using a thermodynamic diagram. Inputing values of surface temperature, surface pressure and specific humidity to the HP results in a lifting condensation level. The LCL is the height at which a parcel, when lifted dry-adiabatically, becomes saturated. The program uses the Clausius-Clapeyron equation to arrive at a final expression for the LCL that is determined by values of surface temperature, surface pressure and specific humidity.

II. Computation of Surface Winds

A. Objectives

This program will give the forecaster, either ship-board or at a regional center, an easy and accurate method of computing the geostrophic, gradient and estimated surface wind from a MSL pressure analysis or model .forecast. This method is more complete than a graphical geostrophic wind scale overlay.

B. Principles

The geostrophic wind speed and direction are obtained from the east-west (u_g) and north-south (v_g) components.

$$u_g = - \frac{1}{f\rho} \frac{\partial p}{\partial y} \qquad |v_g| = \sqrt{u^2_g + v^2_g}$$

$$v_g = \frac{1}{f\rho} \frac{\partial p}{\partial x} \qquad \tan \theta_g = \frac{v_g}{u_g}$$

where u_g and v_g are geostrophic wind components,

$f = 2\,\Omega \sin \phi$; is latitude of forecast point,

$\rho = 1.3$ kg/m³; typical sea level density value,

$\partial x, \partial y = 1°$ lat = 111 km

Figure 1

Geostrophic wind ($\vec{V_g}$) computed by the finite differencing scheme with 1° latitude grid spacing.

3
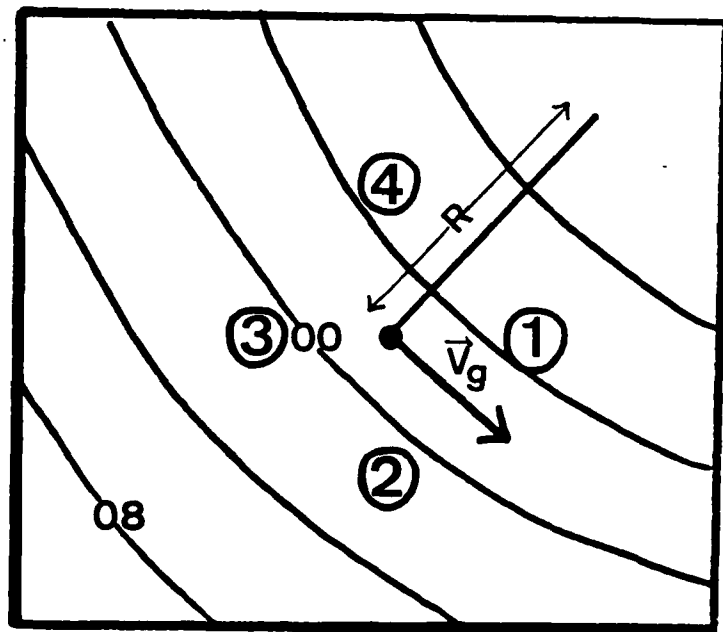
The user enters the latitude and longitude of the point (Northern Hemisphere) where a wind is desired. Next, the user enters four pressures that are 1° latitude north, south, east and west of the center point used in the finite differencing technique:

$$\frac{\partial p}{\partial y} = \frac{P\textcircled{4} - P\textcircled{2}}{222 \text{ km}} \quad ; \quad \frac{\partial P}{\partial x} = \frac{P\textcircled{1} - P\textcircled{3}}{222 \text{ km}} \quad . \qquad \text{(See Figure 1.)}$$

The gradient wind speed is obtained from the geostrophic wind speed and the radius of curvature (R).

$$|V_{gr}| = \frac{|V_g|}{.5 + \sqrt{25 + V_g/fR}} \qquad \begin{array}{ll} \text{where } R > 0 & \text{cyclonic} \\ R < 0 & \text{anticyclonic} \end{array}$$

The user enters a radius of curvature (in kilometers) which is representative of the isobaric curvature in the forecast area. (See Figure 1.)

In a cyclonic situation (R > 0), the magnitude of the gradient wind is less than the magnitude of the geostrophic wind (subgeostrophic); if R < 0 (anticyclonic), the gradient wind speed is greater than the geostrophic (supergeostrophic). If the curvature is zero (R = ∞) the magnitude of the gradient and geostrophic winds is the same. Regardless of the curvature, the gradient wind is from the same direction as the geostrophic wind.

The estimated surface wind speed and direction are obtained from the gradient speed and direction using Ekman layer assumptions. Over the land, the gradient wind speed is multiplied by a factor of 0.6 which is an approximate amount that the speed is reduced by friction. The resulting speed is an estimated surface wind speed. The actual direction is rotated counter-clockwise 20° from the original direction. Over the sea, the gradient wind speed is multiplied by .81 and direction is rotated by 10°. The oceanic and land frictional effects follow the observational summary of Sheppard (1969) and the discussion of Petterssen (1956) and Haltiner and Martin (1957). Sheppard (1969) and Mendenhall (1967) indicate 10° is a reasonable estimate of

frictional veering over the ocean from weather ship data. Over land, the frictional effects are naturally heavily dependent upon surface roughness so the 20° veering is only a general estimate.

C.   User's Guide

1)   Make sure the calculator and printer (NOR mode) are on.

2)   [XEQ] [alpha] SIZE [alpha]

will prompt SIZE __ __ __

3)   Type 100.

4)   Enter magnetic cards as labelled 1-9 - -

5)   After the program (WIND) is "WORKING" and entered, it is ready to be executed.

6)   [XEQ] [alpha] WIND [alpha]

7)   The prompt CTR LAT? will appear.

8)   Press the [R/S] button to continue.

(Do this each time you answer a prompt.)

9)   The prompt CTR LON? will appear.

Enter the longitude of the center forecast point.

10) Press [R/S]

11) Answer the prompts for the four pressures (mb).

12) Press [R/S] . (Remember to do this each time.)

13) The geostrophic wind speed (m/s) and direction will be displayed.

14) Enter a radius of curvature (m) after prompt RADIUS?

15) The gradient wind speed will be displayed.

16) The prompt LAND or SEA? will appear.

If the forecast region is over land, enter "LAND"; otherwise, enter "SEA".

17) The estimated surface wind speed and direction will be displayed and the program is done.

18) To run the program again: $\boxed{\text{XEQ}}$ $\boxed{\text{alpha}}$ WIND $\boxed{\text{alpha}}$

D.   Examples

To illustrate the use of the program the surface wind will be estimated

for points A and B in Figure 2.. The observed surface wind speed and direction

for forecast point A at 0000Z on 26 November 1981 is 10 m/s from 315°. For

point B, the surface wind speed is 20 m/s from 295°.

Execution of the "WIND" program on the HP-41CV calculator results in a

surface wind speed of 14 m/s from a northwest direction of 319° for forecast

point A. Entering the latitude/longitude position (43N 130 W) along with four

pressures 1° latitude north, south, east and west (1007 mb, 1012 mb, 1009 mb,

1012mb respectively) results in a geostrophic wind of 20 m/s from 329°. A

radius of curvature of 1,100 km allows a gradient wind to be computed (18

m/s).   Finally, since forecast point A is an ocean location, the   oceanic

Ekman layer boundary assumptions are applied. The resulting estimated surface

wind is 14 m/s from 319°.   This estimated wind is in agreement with the

observed real   wind speed (10 m/s) and direction (315°).

For forecast point B (46N 135W) the four pressures (1008 mb, 1011 mb,

1006.5 mb and 1013 mb) result in a geostrophic wind of 24 m/s from 295°.

From the radius of curvature (1,300 km), a gradient wind of 21 m/s is

calculated.   The final estimated wind speed for this ocean location is 17 m/s

from 285°   which compares with the observed real wind speed (20 m/s) and

direction (295°).
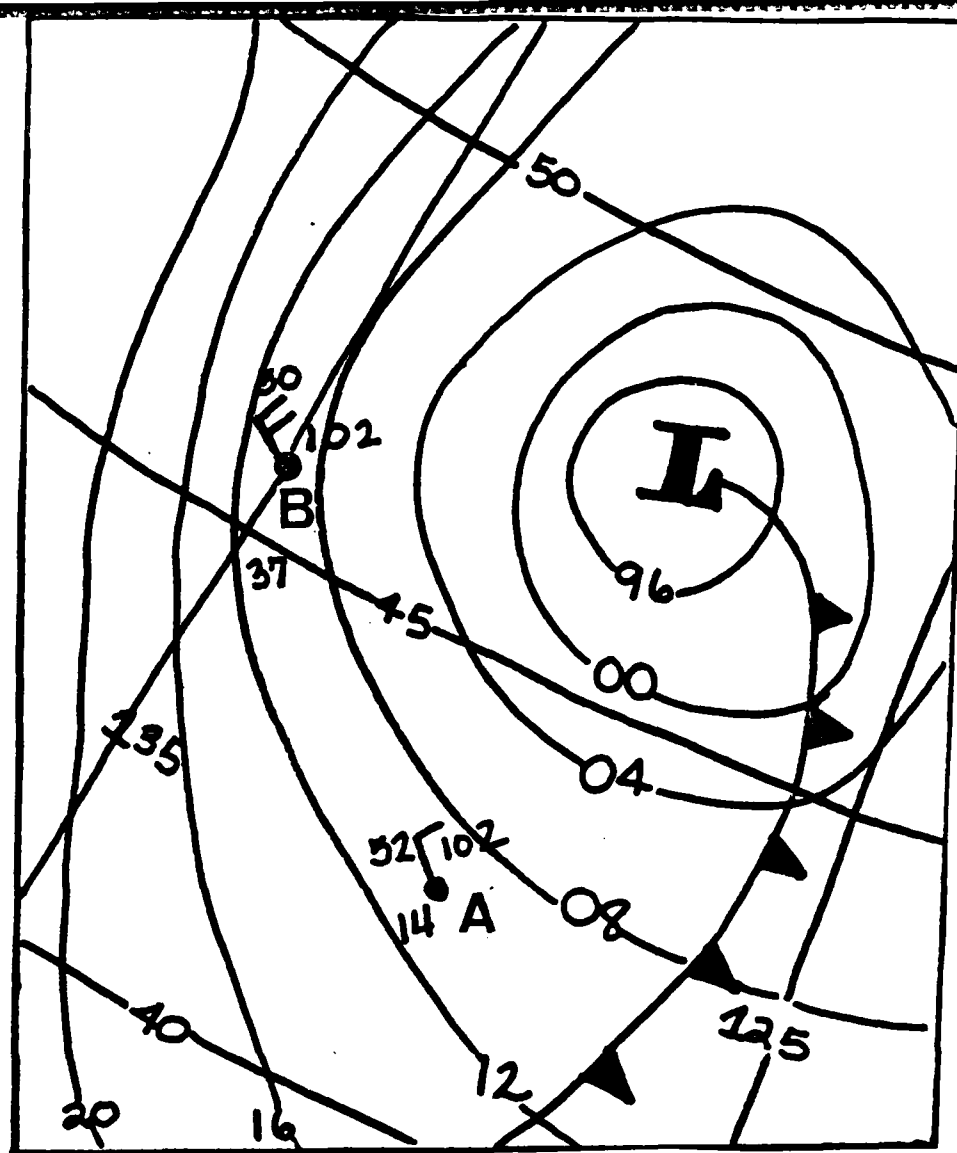
Figure 2

Surface conditions observed at 0000Z 26 November, 1981 for illustration of surface wind program.

A

	XEQ "WIND"	GEO. SPEED:	
			20.
CTR LAT?		GEO. DIR FROM:	
	43.		329.
CTR LON?		RADIUS?	
	130.		1,100,000.
PRS NO LAT?		GRAD. SPEED:	
	1,007.		18.
PRS SO LAT?		LAND OR SEA?	
	1,012.	SEA	
PRS EAST LAT?		SFC SPEED:	
	1,009.		14.
PRS WEST LAT?		SFC DIR FROM:	
	1,012.		219.

B

	XEQ "WIND"	GEO. SPEED:	
			24.
CTR LAT?		GEO. DIR FROM:	
	46.		295.
CTR LON?		RADIUS?	
	135.		1,300,000.
PRS NO LAT?		GRAD. SPEED:	
	1,008.		21.
PRS SO LAT?		LAND OR SEA?	
	1,011.	SEA	
PRS EAST LAT?		SFC SPEED	
	1,006.5		17.
PRS WEST LAT?		SFC DIR FROM:	
	1,013.		255.

E. **Program**

Table I
Surface Winds Program.

LBL "WIND"	/	101 ATAN	151 STO 18
FIX 0	1.3	102 180	152 GTO "GRAD"
"CTR LAT?"	/	103 +	153 LBL "EAST"
04 PRUMPT	54 RCL 08	104 STO 18	154 90.0
05 STO 01	55 /	105 GTO "GRAD"	155 STO 18
06 "CTR LON?"	56 STO 10	106 LBL "WSN"	156 GTO "GRAD"
07 PROMPT	57 RCL 09	107 0	157 LBL "GRAD"
08 STO 02	58 ENTER↑	108 ENTER↑	158 "GEO. DIR FROM:"
09 "PRS NO. LAT?"	59 X↑2	109 RCL 10	159 AVIEW
10 PROMPT	60 RCL 10	110 X>Y?	160 PSE
11 STO 03	61 X↑2	111 GTO "TRE"	161 RCL 18
12 "PRS SO. LAT?"	62 +	112 1/X	162 VIEW 18
13 PROMPT	63 SQRT	113 RCL 09	163 PSE
14 STO 04	64 STO 11	114 *	164 "RADIUS?"
15 "PRS EAST LAT?"	65 "GEO. SPEED:"	115 ATAN	165 PROMPT
16 PROMPT	66 AVIEW	116 CHS	166 STO 25
17 STO 05	67 PSE	117 270	167 0
18 "PRS WEST LAT?"	68 RCL 11	118 +	168 ENTER↑
19 PROMPT	69 VIEW 11	119 STO 18	169 RCL 25
20 STO 06	70 PSE	120 GTO "GRAD"	170 X<=Y?
21 RCL 03	71 0	121 LBL "TRE"	171 GTO "ANTI"
22 ENTER↑	72 ENTER↑	122 1/X	172 RCL 11
23 RCL 04	73 RCL 09	123 RCL 09	173 RCL 25
24 -	74 X=Y?	124 *	174 /
25 100	75 GTO "CHK"	125 ATAN	175 RCL 08
26 *	76 0	126 CHS	176 /
27 2.22 E05	77 ENTER↑	127 270	177 .25
28 /	78 RCL 10	128 +	178 +
29 1.3	79 X=Y?	129 STO 18	179 SQRT
30 /	80 GTO "CHKS"	130 GTO "GRAD"	180 .5
31 CHS	81 0	131 LBL "CHK"	181 +
32 STO 07	82 ENTER↑	132 0	182 STO 26
33 RCL 01	83 RCL 09	133 ENTER↑	183 RCL 11
34 ENTER↑	84 X>Y?	134 RCL 10	184 RCL 26
35 SIN	85 GTO "WSN"	135 X<=Y?	185 /
36 1.4584 E-04	86 0	136 GTO "NOR"	186 STO 27
37 *	87 ENTER↑	137 180.0	187 GTO "ACT"
38 STO 08	88 RCL 10	138 STO 18	188 LBL "ANTI"
39 RCL 07	89 X>Y?	139 GTO "GRAD"	189 RCL 11
40 ENTER↑	90 GTO "TWO"	140 LBL "NOR"	190 RCL 25
41 RCL 08	91 1/X	141 360.0	191 /
42 /	92 RCL 09	142 STO 18	192 RCL 08
43 STO 09	93 *	143 GTO "GRAD"	193 /
44 RCL 05	94 ATAN	144 LBL "CHKS"	194 STO 20
45 ENTER↑	95 STO 18	145 0	195 RCL 20
46 RCL 06	96 GTO "GRAD"	146 ENTER↑	196 ENTER↑
47 -	97 LBL "TWO"	147 RCL 09	197 .25
48 100	98 1/X	148 X<=Y?	198 +
49 *	99 RCL 09	149 GTO "EAST"	199 STO 28
50 2.22 E05	100 *	150 270.0	200 0

9

```
201 ENTER↑
202 RCL 29
203 X>Y?
204 GTO "OK"
205 "BAD RAD"
206 AVIEW
207 GTO "END"
208◆LBL "OK"
209 SQRT
210 .5
211 +
212 STO 29
213 RCL 11
214 RCL 29
215 /
216 STO 27
217◆LBL "ACT"
218 "GRAD. SPEED:"
219 AVIEW
220 PSE
221 RCL 27
222 VIEW 27
223 PSE
224 "LAND OR SEP?"
225 AON
226 PROMPT
227 AOFF
228 ASTO Y
229 "LAND"
230 ASTO IND X
231 X=Y?
232 GTO "LAND"
233 RCL 27
234 ENTER↑
235 .01
236 *
237 STO 32
238 "SFC SPEED:"

239 AVIEW
240 PSE
241 RCL 32
242 VIEW 32
243 RCL 18
244 ENTER↑
245 10
246 -
247 STO 33
248 "SFC DIR FROM:"
249 AVIEW
250 PSE
251 RCL 33
252 VIEW 33
253 GTO "END"
254◆LBL "LAND"
255 RCL 27
256 ENTER↑
257 .6
258 *
259 STO 30
260 "SFC SPEED:"
261 AVIEW
262 PSE
263 RCL 30
264 VIEW 30
265 RCL 18
266 ENTER↑
267 20
268 -
269 STO 31
270 "SFC DIR FROM:"
271 AVIEW
272 PSE
273 RCL 31
274 VIEW 31
275◆LBL "END"
276 "END"
277 .END.
```

III. Determining the Probability of Precipitation for Monterey, California

A. Objective

To determine the probability of 24-h rainfall for a regional area (Monterey, California) for the period 0800 PST forecast day to 0800 PST of the following day, for the wet-season months, November through April. This procedure is based on Renard's (1972) honogram method and statistics.

B. Principles

General Forecast Procedure. The probability of 24-h rainfall is determined by values of geostrophic relative vorticity and sea-level pressures at different locations.

A first forecast parameter is obtained by taking the sea-level pressure at Eureka, CA (P_{Eureka}) and the difference between the 500 mb geostrophic relative vorticity at Monterey (ζ_M) and a point $8°$ latitude upstream from Monterey (ζ_8). Enter these values into a pre-established statistical table, which is stored on the calculator, to arrive at a forecast variable, Y_1. (See Figure 4.)

A second forecast parameter, Y_2, is the value that results from taking the sea-level pressure difference between Monterey and Eureka ($\Delta P_{M-Eureka}$) and Monterey and Las Vegas (ΔP_{M-LV}). (See Figure 5). These two parameters, Y_1 and Y_2, are entered in a third table (Figure 6) which results in a final value that corresponds to a probability of average rainfall for the Monterey Peninsula.

500 mb Geostrophic Relative Vorticity. To calculate the 500 mb geostrophic relative vorticity, five 500 mb heights are needed to use finite differencing technique to solve ($\zeta_M = g/f \, \nabla^2 Z$) where M is the geostrophic relative vorticity at Monterey, $\nabla^2 Z$ is the Laplacian of the 500 mb height. For example, in Figure 3 at Monterey ($Z_M = 558$ dm) the four 500 mb heights

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are 552 dm (Z_n: 500 mb height to the north), 566 dm (Z_s), 560 dm (Z_e), and 563 dm (Z_w) with a grid spacing of 6° latitude. This results in a geostrophic relative vorticity of 1.8×10^{-5} sec^{-1}.

Figure 3

Computation of geostrophic relative vorticity for Monterey (ζ_M) and a point 8° latitude upstream (ζ_8).
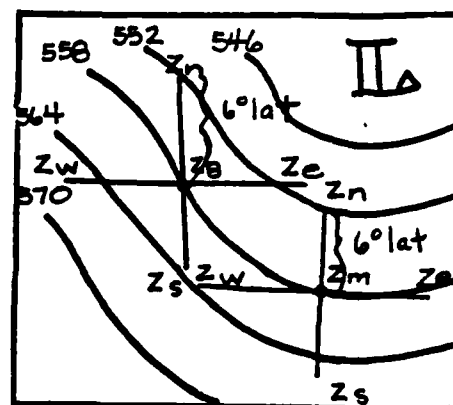
The 500 mb geostrophic relative vorticity is computed for a point 8° latitude upstream (8° corresponds to a typical daily progression of short-waves in the westerlies of 22 kt during the winter season) from Monterey in the same way. The difference between the two vorticities ($\zeta_{8°} - \zeta_M$) is used as a forecast factor.

<u>Sea-Level Pressure</u>. Y_1, a first forecast parameter, is obtained from the computed vorticity difference and a sea-level pressure at Eureka, California (Figure 4). Y_2, a second forecast parameter, is obtained from the difference between the sea-level pressure at Monterey minus the sea-level pressure at Eureka ($\Delta P_{M-Eureka}$) and the sea-level pressure at Monterey minus the sea-level pressure at Las Vegas (ΔP_{M-LV}) (Figure 5).

<u>Probability of Rainfall</u>. From the two forecast parameters, Y_1 and Y_2, a value Y_3 is obtained which corresponds to a probability of rainfall for the Monterey, CA area for the period 0800 PST forecast day to 0800 PST of the following day, for the wet-season months, November through April. (Figure 6.) The corresponding values between Y_3 and a probability of average rainfall are on data cards that are entered during the program execution.

P_{Eureka}

Figure 4

$Y_1 = f(P_{Eureka}, \zeta_8 - \zeta_M)$: first forecast factor of the raincaster.

ΔP_{M-LV}

$\Delta P_{M-Eureka}$

Figure 5

$Y_2 = f(\Delta P_{M-Eureka}, \Delta P_{M-LV})$: second forecast factor of the raincaster.

Figure 6

$Y_3 = f(Y_1, Y_2)$: third forecast factor of the raincaster.

Y_2

Y_1

C.   User's Guide

1)   Make sure the printer is attached and in the NOR mode. Both printer and
      calculator should be on and the calculator's memory cleared.

2)   ☐XEQ ☐alpha SIZE ☐alpha
      will prompt SIZE __ __ __

3)   Type 035.

4)   Load the program cards (1-18). Continue after the prompt "WORKING."

5)   ☐XEQ ☐alpha RAIN ☐alpha

6)   Enter 500 mb heights (dm) for each prompt. (For example, ZN: 8° means
      height at north position at a point 8° latitude upstream from Monterey.)

7)   Hit ☐R/S after each entry.

8)   Enter pressure values for Monterey, Las Vegas, and Eureka.

9)   Hit ☐R/S after each entry.

10)   A data card prompt will occur after all the information has been entered.
      For the first time, use data set #1; the second time, use data set #2,
      etc.

11)   The final number that appears after all data card insertion instructions
      is the probability of average rainfall for the Monterey Peninsula.

      NOTE: If the program ends with "OUT OF RANGE", then the values used are
             either too small or too large.   Try another set of values that
             will fit in the stored data sets.

D.   Examples

Example A illustrates the use of the program "RAIN" in determining the probability of precipitation at Monterey, CA. At 1200Z 25 November 1981 for a point 8° latitude upstream from Monterey, the 500 mb heights (in decameters) 6° latitude to the north, east, south, west and at the center point are 541.0, 543.0, 562.5, 563.0 and 555.0 respectively. (See Figure 7.) Around Monterey, the 500 mb heights are 550.0 dm 6° latitude to the north, 555.0 dm at the eastern location, 573.0 dm to the south, 576.0 dm to the west, and 567.0 dm at Monterey. These heights are used to obtain the 500 mb relative geostrophic vorticity values used in generating forecast variables. The 1200Z sea-level pressures at Monterey, Las Vegas and Eureka (1018.8 mb, 1006.2 mb, 1017.3 mb) are also required to compute forecast variables. (See Figure 8a.) These forecast variables result in a probability of precipitation of 90%. Rain did verify during the 24-h period, as noted from the 1200Z 26 November 1981 observation (Figure 8b.)

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A
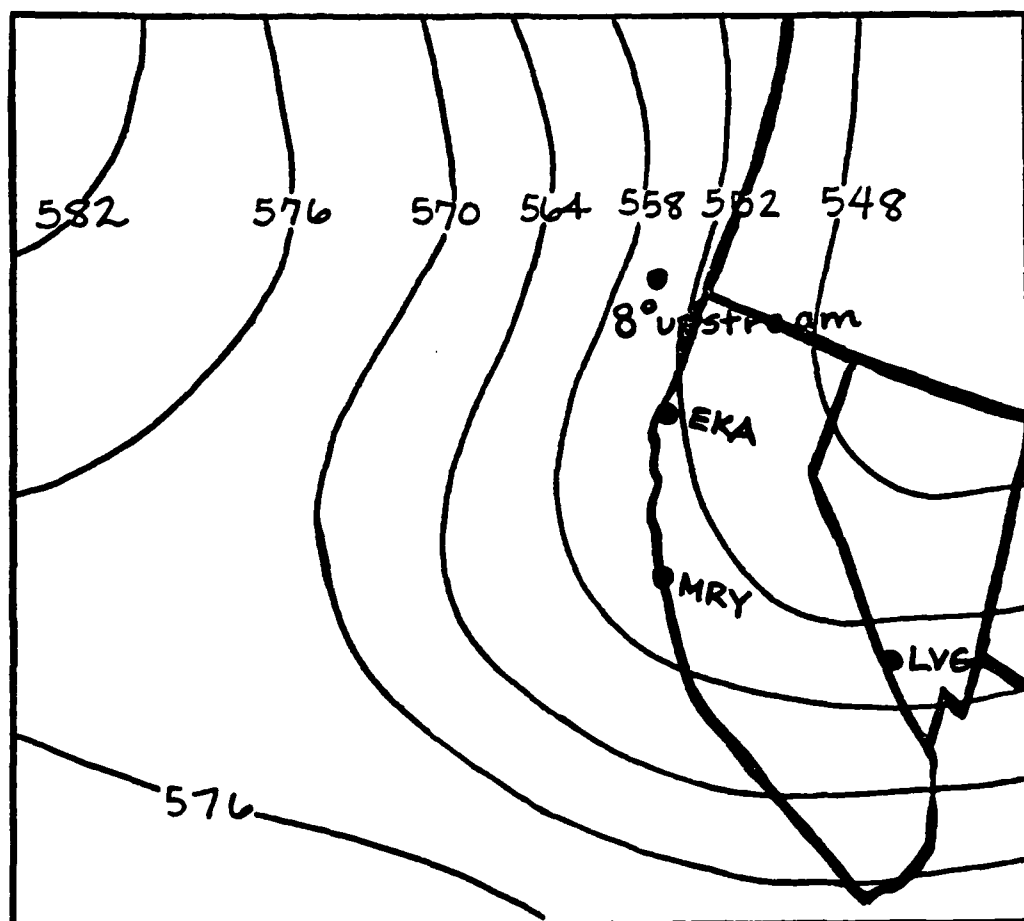
Figure 7
500 mb analysis for
1200Z 25 November 1981
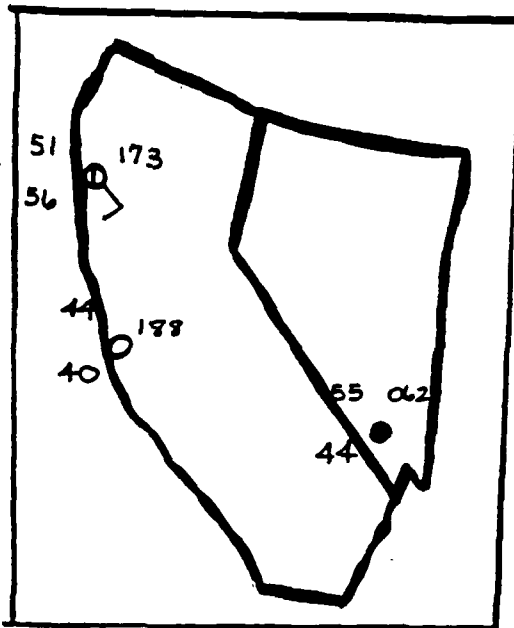
Figure 8a
Surface observations
for 1200Z 25 November 1981
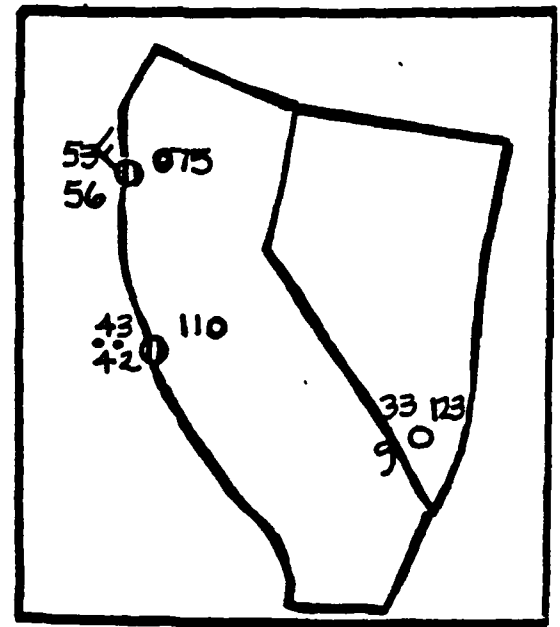
Figure 8b
Surface observations
for 1200Z 26 November 1981

Table II
Example of the Probability of Precipitation for Monterey, California
Program.

```
ENTER ZN 8
            541.
ENTER ZE 8
            543.
ENTER ZS 8
            562.5
ENTER ZW 8
            563.
ENTER Z0 8
            555.
ENTER ZN M
            548.
ENTER ZE M
            554.
ENTER ZS M
            569.5
ENTER ZW M
            570.5
ENTER Z0 M
            555.
```

```
ENTER PRES MONT
            1.018.8
ENTER PRES LVGS
            1.006.2000
ENTER PRES ERKA
            1.017.3000
            Y1= 1.018.0000
            X2=-33.0000
            X3= 2.0000
            X4= 14.0000
INSERT CFD 13
            Y1=-20.0000
INSERT CFD 3
            Y2= 25.0000
            90.0000
```

Probability of
Precipitation is 90%.
Data verified from
observed case at
1200Z 26 November 1981.

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E. Program

Table III
Probability of 24-h Precipitation for Monterey, California Program.

01 LBL "RAIN"	51 RCL 01	101 -	151 GTO 06	201 LBL 08
02 "ENTER ZN:8"	52 +	102 STO 02	152 XEQ 00	202 20.035
03 PROMPT	53 CHS	103 GTO 77	153 X=Y?	203 "INSERT CRD 1"
04 STO 00	54 RCL 00	104 LBL 87	154 GTO 09	204 AVIEW
05 "ENTER ZE:8"	55 +	105 RCL 02	155 XEQ 00	205 RDTAX
06 PROMPT	56 STO 02	106 1	156 X=Y?	206 FS? 00
07 RCL 00	57 "ENTER PRES MONT"	107 +	157 GTO 10	207 GTO 33
08 +	58 PROMPT	108 STO 02	158 XEQ 00	208 FS? 01
09 STO 00	59 XEQ "ROUND"	109 GTO 77	159 X=Y?	209 GTO 44
10 "ENTER ZS:8"	60 STO 03	110 LBL 86	160 GTO 11	210 GTO 24
11 PROMPT	61 "ENTER PRES LVGS"	111 RCL 02	161 XEQ 00	211 LBL 09
12 RCL 00	62 PROMPT	112 "X2="	162 X=Y?	212 20.035
13 +	63 XEQ "ROUND"	113 ACA	163 GTO 12	213 "INSERT CPD 2"
14 STO 00	64 STO 04	114 ACX	164 XEQ 00	214 AVIEW
15 "ENTER ZW:8"	65 "ENTER PRES ERKA"	115 ADV	165 X=Y?	215 RDTAX
16 PROMPT	66 PROMPT	116 RCL 03	166 GTO 13	216 FS? 00
17 RCL 00	67 XEQ "ROUND"	117 RCL 01	167 XEQ 00	217 GTO 33
18 +	68 STO 01	118 -	168 X=Y?	218 FS? 01
19 STO 00	69 RCL 01	119 XEQ "FIXEVEN"	169 GTO 14	219 GTO 44
20 "ENTER Z0:8"	70 2	120 RCL 05	170 XEQ 00	220 GTO 24
21 PROMPT	71 MOD	121 STO 00	171 X=Y?	221 LBL 10
22 4	72 X=0?	122 "X3="	172 GTO 15	222 20.035
23 *	73 GTO 85	123 ACA	173 XEQ 00	223 "INSERT CPD 3"
24 CHS	74 RCL 01	124 ACX	174 X=Y?	224 AVIEW
25 RCL 00	75 1	125 ADV	175 GTO 16	225 RDTAX
26 +	76 +	126 RCL 03	176 FS? 00	226 FS? 00
27 STO 00	77 STO 01	127 RCL 04	177 GTO 23	227 GTO 33
28 "ENTER ZN:M"	78 GTO 85	128 -	178 XEQ 00	228 FS? 01
29 PROMPT	79 LBL 85	129 XEQ "FIXEVEN"	179 X=Y?	229 GTO 44
30 STO 01	80 RCL 01	130 RCL 05	180 GTO 17	230 GTO 24
31 "ENTER ZE:M"	81 "X1="	131 STO 04	181 XEQ 00	231 LBL 11
32 PROMPT	82 ACA	132 "X4="	182 X=Y?	232 20.035
33 RCL 01	83 ACX	133 ACA	183 GTO 18	233 "INSERT CRD 4"
34 +	84 ADV	134 ACX	184 XEQ 00	234 AVIEW
35 STO 01	85 RCL 02	135 ADV	185 X=Y?	235 RDTAX
36 "ENTER ZS:M"	86 XEQ "ROUND"	136 994	186 GTO 19	236 FS? 00
37 PROMPT	87 STO 02	137 STO 07	187 XEQ 00	237 GTO 33
38 RCL 01	88 LBL 77	138 27	188 X=Y?	238 FS? 01
39 +	89 RCL 02	139 STO 08	189 GTO 20	239 GTO 44
40 STO 01	90 3	140 2	190 XEQ 00	240 GTO 24
41 "ENTER ZW:M"	91 MOD	141 STO 09	191 X=Y?	241 LBL 12
42 PROMPT	92 X=0?	142 RCL 00	192 GTO 21	242 20.035
43 RCL 01	93 GTO 86	143 STO 03	193 XEQ 00	243 "INSERT CRD 5"
44 +	94 1	144 RCL 01	194 X=Y?	244 AVIEW
45 STO 01	95 X=Y?	145 GTO 40	195 GTO 22	245 RDTAX
46 "ENTER Z0:M"	96 GTO 88	146 LBL 40	196 GTO 23	246 XROM 28.33
47 PROMPT	97 GTO 87	147 RCL 07	197 LBL 00	247 PCL 01
48 4	98 LBL 88	148 X>Y?	198 RCL 09	248 FS? 01
49 *	99 RCL 02	149 GTO 23	199 +	249 GTO 44
50 CHS	100 1	150 X=Y?	200 RTN	250 GTO 24

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```
251◆LBL 13          301◆LBL 18          351 GTO 51          401 STO 06          451 GTO 35
252 20.035          302 20.035          352 XEQ 25          402 5               452 RCL 06
253 "INSERT CRD 6"  303 "INSERT CRD 11" 353 X=Y?            403 MOD             453 STO 10
254 AVIEW           304 AVIEW           354 GTO 52          404 STO 13          454 "Y1="
255 RDTAX           305 RDTAX           355 XEQ 25          405 X=0?            455 ACA
256 AVIEW           306 XROM 28,33      356 X=Y?            406 GTO 31          456 ACX
257 XROM 28,33      307 X>0?            357 GTO 53          407 RCL 13          457 ADV
258 GTO 33          308 RCL 12          358 XEQ 25          408 1               458 -2
259 FS? 01          309 GTO 24          359 X=Y?            409 X=Y?            459 STO 07
260 GTO 44          310◆LBL 19          360 GTO 54          410 GTO 30          460 10
261 GTO 24          311 20.035          361 XEQ 25          411 RCL 13          461 STO 08
262◆LBL 14          312 "INSERT CRD 12" 362 X=Y?            412 2               462 2
263 20.035          313 AVIEW           363 GTO 55          413 X=Y?            463 STO 09
264 "INSERT CRD 7"  314 RDTAX           364 XEQ 25          414 GTO 29          464 SF 00
265 AVIEW           315 GTO 44          365 X=Y?            415 RCL 13          465 RCL 03
266 RDTAX           316 XROM 28,33      366 GTO 56          416 3               466 GTO 40
267 XROM 28,33      317 GTO 24          367 XEQ 25          417 X=Y?            467◆LBL 32
268 GTO 33          318◆LBL 20          368 X=Y?            418 GTO 28          468 RCL 06
269 FS? 01          319 20.035          369 GTO 57          419 RCL 13          469 STO 12
270 GTO 44          320 "INSERT CRD 13" 370 XEQ 25          420 4               470 "Y2="
271 GTO 24          321 AVIEW           371 X=Y?            421 X=Y?            471 ACA
272◆LBL 15          322 RDTAX           372 GTO 58          422 GTO 27          472 ACX
273 20.035          323 FS? 01          373 XEQ 25          423◆LBL 27          473 ADV
274 "INSERT CRD 8"  324 GTO 44          374 X=Y?            424 RCL 06          474 0
275 AVIEW           325 GTO 24          375 GTO 59          425 1               475 STO 07
276 RDTAX           326◆LBL 21          376 XEQ 25          426 +               476 70
277 GTO 33          327 20.035          377 X=Y?            427 STO 06          477 STO 08
278 FS? 33          328 "INSERT CRD 14" 378 GTO 60          428 GTO 31          478 5
279◆LBL 00          329 AVIEW           379 XEQ 25          429◆LBL 28          479 STO 09
280 GTO 44          330 RDTAX           380 X=Y?            430 RCL 06          480 SF 01
281 GTO 24          331 AVIEW           381 GTO 61          431 2               481 CF 00
282◆LBL 16          332 XROM 28,33      382 XEQ 25          432 +               482 RCL 10
283 20.035          333 GTO 44          383 X=Y?            433 STO 06          483 GTO 40
284 "INSERT CRD 9"  334 GTO 24          384 GTO 62          434 GTO 31          484◆LBL 23
285 AVIEW           335◆LBL 22          385 XEQ 25          435◆LBL 29          485 FS? 01
286 RDTAX           336 20.035          386 X=Y?            436 RCL 06          486 GTO "END"
287 XROM 28,33      337 "INSERT CRD 15" 387 GTO 63          437 2               487 "OUT OF RANGE"
288 RCL 01          338 AVIEW           388 XEQ 25          438 -               488 AVIEW
289 FS? 01          339 RDTAX           389 X=Y?            439 STO 06          489 RTN
290 GTO 44          340 GTO d           390 GTO 64          440 GTO 31          490◆LBL "END"
291 GTO 24          341 XROM 28,33      391 XEQ 25          441◆LBL 30          491 FS? 02
292◆LBL 17          342 RCL 12          392 X=Y?            442 RCL 06          492 GTO 99
293 20.035          343 GTO 24          393 GTO 65          443 1               493 SF 02
294 "INSERT CRD 10" 344◆LBL 24          394 GTO 26          444 -               494 RCL 06
295 AVIEW           345 RCL 02          395◆LBL 25          445 STO 06          495 1
296 RDTAX           346 RCL 08          396 3               446 GTO 31          496 STO 09
297 XROM 28,33      347 X=Y?            397 -               447◆LBL 31          497 XEQ 00
298◆LBL 00          348 GTO 50          398 RTN             448 FS? 00          498 X>Y?
299 GTO 44          349 XEQ 25          399◆LBL 26          449 GTO 32          499 GTO 66
300 GTO 24          350 X=Y?            400 XEQ "ROUND"     450 FS? 01          500 XEQ 00
```

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```
501 X>Y?        551 40          601 X=Y?        651 GTO 60       701 GTO 26       751 75
502 GTO 67      552 X>Y?        602 GTO 61      652 XEQ 00       702♦LBL 62       752 GTO 23
503 XEQ 00      553 GTO 83      603 XEQ 00      653 X=Y?         703 RCL 32       753♦LBL 80
504 X>Y?        554 GTO 84      604 X=Y?        654 GTO 61       704 GTO 26       754 80
505 GTO 68      555 RTN         605 GTO 62      655 XEQ 00       705♦LBL 63       755 GTO 23
506 XEQ 00      556♦LBL 99      606 GTO 63      656 X=Y?         706 RCL 33       756♦LBL 81
507 X>Y?        557 ACX         607 GTO 26      657 GTO 62       707 GTO 26       757 85
508 GTO 69      558 ADV         608♦LBL 35      658 XEQ 00       708♦LBL 64       758 GTO 23
509 XEQ 00      559 CF 01       609 RCL 06      659 X=Y?         709 RCL 34       759♦LBL 82
510 X>Y?        560 CF 02       610 "Y3="       660 GTO 63       710 GTO 26       760 90
511 GTO 70      561 RTN         611 ACA         661 XEQ 00       711♦LBL 65       761 GTO 23
512 XEQ 00      562♦LBL 33      612 ACX         662 X=Y?         712 RCL 35       762♦LBL 83
513 X>Y?        563 -2          613 ADV         663 GTO 64       713 GTO 26       763 95
514 GTO 71      564 STO 09      614 GTO 23      664 GTO 65       714♦LBL 66       764 GTO 23
515 XEQ 00      565 RCL 04      615♦LBL 44      665 GTO 26       715 10           765♦LBL 84
516 X>Y?        566 RCL 08      616 -5          666♦LBL 50       716 GTO 23       766 100
517 GTO 72      567 X=Y?        617 STO 09      667 RCL 20       717♦LBL 67       767 GTO 23
518 XEQ 00      568 GTO 50      618 RCL 12      668 GTO 26       718 15           768♦LBL "ROUND"
519 X>Y?        569 XEQ 00      619 RCL 08      669♦LBL 51       719 GTO 23       769 FIX 0
520 GTO 73      570 X=Y?        620 X=Y?        670 RCL 21       720♦LBL 68       770 RND
521 XEQ 00      571 GTO 51      621 GTO 50      671 GTO 26       721 25           771 FIX 4
522 X>Y?        572 XEQ 00      622 XEQ 00      672♦LBL 52       722 GTO 23       772 RTN
523 GTO 74      573 X=Y?        623 X=Y?        673 RCL 22       723♦LBL 69       773♦LBL "FIXEVEN"
524 XEQ 00      574 GTO 52      624 GTO 51      674 GTO 26       724 30           774 STO 05
525 X>Y?        575 XEQ 00      625 XEQ 00      675♦LBL 53       725 GTO 23       775 2
526 GTO 75      576 X=Y?        626 X=Y?        676 RCL 23       726♦LBL 70       776 MOD
527 XEQ 00      577 GTO 53      627 GTO 52      677 GTO 26       727 35           777 X=0?
528 X>Y?        578 XEQ 00      628 XEQ 00      678♦LBL 54       728 GTO 23       778 RTN
529 GTO 76      579 X=Y?        629 X=Y?        679 RCL 24       729♦LBL 71       779 RCL 05
530 XEQ 00      580 GTO 54      630 GTO 53      680 GTO 26       730 40           780 1
531 XEQ 00      581 XEQ 00      631 XEQ 00      681♦LBL 55       731 GTO 23       781 +
532 X>Y?        582 X=Y?        632 X=Y?        682 RCL 25       732♦LBL 72       782 STO 05
533 GTO 78      583 GTO 55      633 GTO 54      683 GTO 26       733 45           783 RTN
534 XEQ 00      584 XEQ 00      634 XEQ 00      684♦LBL 56       734 GTO 23       784 .END.
535 XEQ 00      585 X=Y?        635 X=Y?        685 RCL 26       735♦LBL 73
536 X>Y?        586 RCL 26      636 GTO 55      686 GTO 26       736 50
537 GTO 79      587 GTO 56      637 XEQ 00      687♦LBL 57       737 GTO 23
538 XEQ 00      588 XEQ 00      638 X=Y?        688 RCL 27       738♦LBL 74
539 XEQ 00      589 X=Y?        639 GTO 56      689 GTO 26       739 55
540 X>Y?        590 GTO 57      640 XEQ 00      690♦LBL 58       740 GTO 23
541 GTO 80      591 XEQ 00      641 X=Y?        691 RCL 28       741♦LBL 75
542 XEQ 00      592 X=Y?        642 GTO 57      692 GTO 26       742 60
543 XEQ 00      593 GTO 58      643 XEQ 00      693♦LBL 59       743 GTO 23
544 X>Y?        594 XEQ 00      644 X=Y?        694 RCL 29       744♦LBL 76
545 GTO 81      595 X=Y?        645 GTO 58      695 GTO 26       745 65
546 CLX         596 GTO 59      646 XEQ 00      696♦LBL 60       746 GTO 23
547 29          597 XEQ 00      647 X=Y?        697 RCL 30       747♦LBL 78
548 X>Y?        598 X=Y?        648 GTO 59      698 GTO 26       748 70
549 GTO 82      599 GTO 60      649 XEQ 00      699♦LBL 61       749 GTO 23
550 CLX         600 XEQ 00      650 X=Y?        700 RCL 31       750♦LBL 79
```

IV. Contrail Formation

A. Objective

To determine whether or not contrails will form at a certain level in the atmosphere based on the curves from the Contrail Forecasting Manual (Chief of Naval Operations, 1964).

B. Principles

The critical temperature determines if contrails will form at a level. A least squares approximation is given for the critical temperature:

$$T_{crit} = a_1 + a_2 \ln p + a_3 (\ln p)^2 + a_4 RH + a_5 (RH)^2;$$

where:

p is the pressure level;

RH is the relative humidity;

$a_1 = -90.4994$; $a_2 = 3.4232$; $a_3 = 0.5587$; $a_4 = -0.0372$; $a_5 = 0.0012$.

This equation was determined from the curves in Figure 9 of the Contrails Forecasting Manual (Chief of Naval Operations, 1964).

If the ambient temperature is less than the critical temperature, then contrails will form. If the ambient temperature is greater than the critical temperature, then contrails will not form.

There is a narrow range of temperatures where the relative humidity is important. If the dew point is known, the relative humidity can be calculated by using the definitions of saturation vapor pressure (e_s) and relative humidity (R.H.).

$e_s(T) = 6.11 \exp (L/R_w (1/273 - 1/T))$

$R.H. = 100 * (e/e_s)$

where $e_s(T)$ is the saturation vapor pressure

e is the actual vapor pressure

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T is the temperature ($^\circ$K)

L is the latent heat of evaporation (J/kg)

R_w is the specific gas constant for pure water vapor (J/kg $^\circ$K)

If the dew-point temperature is unknown, the relative humidity is estimated and a $\pm 2^\circ$C error margin is assumed when computing the critical temperature. If the ambient temperature is within $\pm 2^\circ$C of the critical temperature, a "probably" will precede the "contrails" or "no contrails" message. The following criteria are used to estimate the relative humidity:

$T_{amb} < T_{crit}$ --> (RH = 0) --> contrails

$T_{amb} < T_{crit}$ --> (RH = 100) --> no contrails

$p < 225$ --> (stratosphere) --> RH $\simeq$ 0%

$p > 300$ --> (not in upper troposphere) --> RH $\simeq$ 40%

$225 < p < 300$ --> (upper troposphere) --> RH $\simeq$ 40%   UNLESS

    cirrus are at this level --> RH $\simeq$ 60%

    flow is known and from

        moist region --> RH $\simeq$ 60%

        dry region --> RH $\simeq$ 0%

C. User's Guide

1) Make sure both the calculator and printer are on and that the printer is set to the MAN mode.

2) [XEQ] [alpha] SIZE [alpha]

3) Prompts SIZE __ __ __; Type 100.

4) Load all three cards, sides 1-6.

5) After "WORKING" signal, program is ready for execution.

6) [XEQ] [alpha] TRAILS [alpha]

7) Program asks about CHANGING FLAGS. For the first run through, leave the flags as they are and continue by hitting the [R/S] key.

8) Enter a pressure level in mb.

9) Press [R/S] key. (Hit [R/S] after each entry.)

10) Enter a temperature in °C.

11) A prompt for a dew—point temperature will be displayed. If T_d is known, type a 1; if T_d is unknown, type a 0.

12) The program will then decide whether or not contrails can be formed at that particular level depending upon the criteria discussed on the preceding pages. If the dew-point temperature is unknown, there might be more "yes" or "no" questions depending upon the pressure level and ambient temperature. Answer "1" for "yes" and "0" for "no."

13) The program will determine whether or not contrails will form at a certain pre-established pressure level.

14) After the answer is displayed, execution can continue for another level by pressing [R/S].

By changing the flags, two options are possible. Setting Flag 1 will make the prompts shorter and less specific. Setting Flag 2 means that the program assumes that the dew-point temperature is known and skips the questions concerning relative humidity estimation.

To change a flag:
a) Press gold button and $\boxed{SF}$ key.

b) Program prompts SF __ __ .

c) Enter either (or both): 01 - short prompt

02 - known T_d

d) To clear flags, press gold button and $\boxed{CF}$ key.

e) Program prompts CF __ __ .

f) Enter 01 or 02 to clear any flag that was set.

The program assumes all flags are clear each time it is first executed.

D. Examples

Examples A-E in Table IV illustrate the use of the program "TRAILS" in deciding whether contrails will form from upper-level sounding data. In example A, where no flags have been set, a pressure of 450 mb and temperature of -35°C are entered in the "TRAILS" program. The dew-point is unknown in this case so a "0" is entered. The program decides that contrails will not be possible with these conditions which agrees with the contrail curve diagram. (See Figure 9.) Example B is similar to A (no flags set and dew point unknown), but contrails will probably form with the particular upper-level sounding data. In example C, no flags are set, but the dew point is known. With a pressure of 250 mb, a temperature of -60.0°C, and dew point of -62.0°C, contrails will form. Examples D and E have flags set, which result in shortened prompts for both cases, and for example E, the dew point is assumed to be known. Both examples D and E illustrate that contrails will not form in these environmental conditions.

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Table IV
Examples of the Contrail Formation Program.

A

```
P=? MB
         450.0000    ***
T=? C
         -35.0000    ***
DO YOU KNOW
DEWPOINT. TD?
YES=ONE
NO=ZERO
KNOW TD?
         0.0000      ***
NO CONTRAILS
```

No flags set
T_d unknown

B

```
P=? MB
         250.0000    ***
T=? C
         -54.0000    ***
DO YOU KNOW
DEWPOINT, TD?
YES=ONE
NO=ZERO
KNOW TD?
         0.0000      ***
ARE THERE
CIRRUS AT
THIS LEVEL?
YES=ONE
NO=ZERO
CIRRUS?
         1.0000      ***
PROBABLY
CONTRAILS
```

No flags set, T_d unknown

C

```
P=? MB
         225.0000    ***
T=? C
         -60.0000    ***
DO YOU KNOW
DEWPOINT, TD?
YES=ONE
NO=ZERO
KNOW TD?
         1.0000      ***
TD=? C
         -62.0000    ***
CONTRAILS
```

No flags set
T_d known

D

```
P=? MB
         300.0000    ***
T=? C
         -48.0000    ***
KNOW TD?
         0.0000      ***
CIRRUS?
         0.0000      ***
KNOW FLOW?
         1.0000      ***
MST OR DRY?
         1.0000      ***
NO CONTRAILS
```

Flag 01 set
Unknown T_d

E

```
P=? MB
         850.0000    ***
T=? C
         -10.0000    ***
TD=? C
         -20.0000    ***
NO CONTRAILS
```
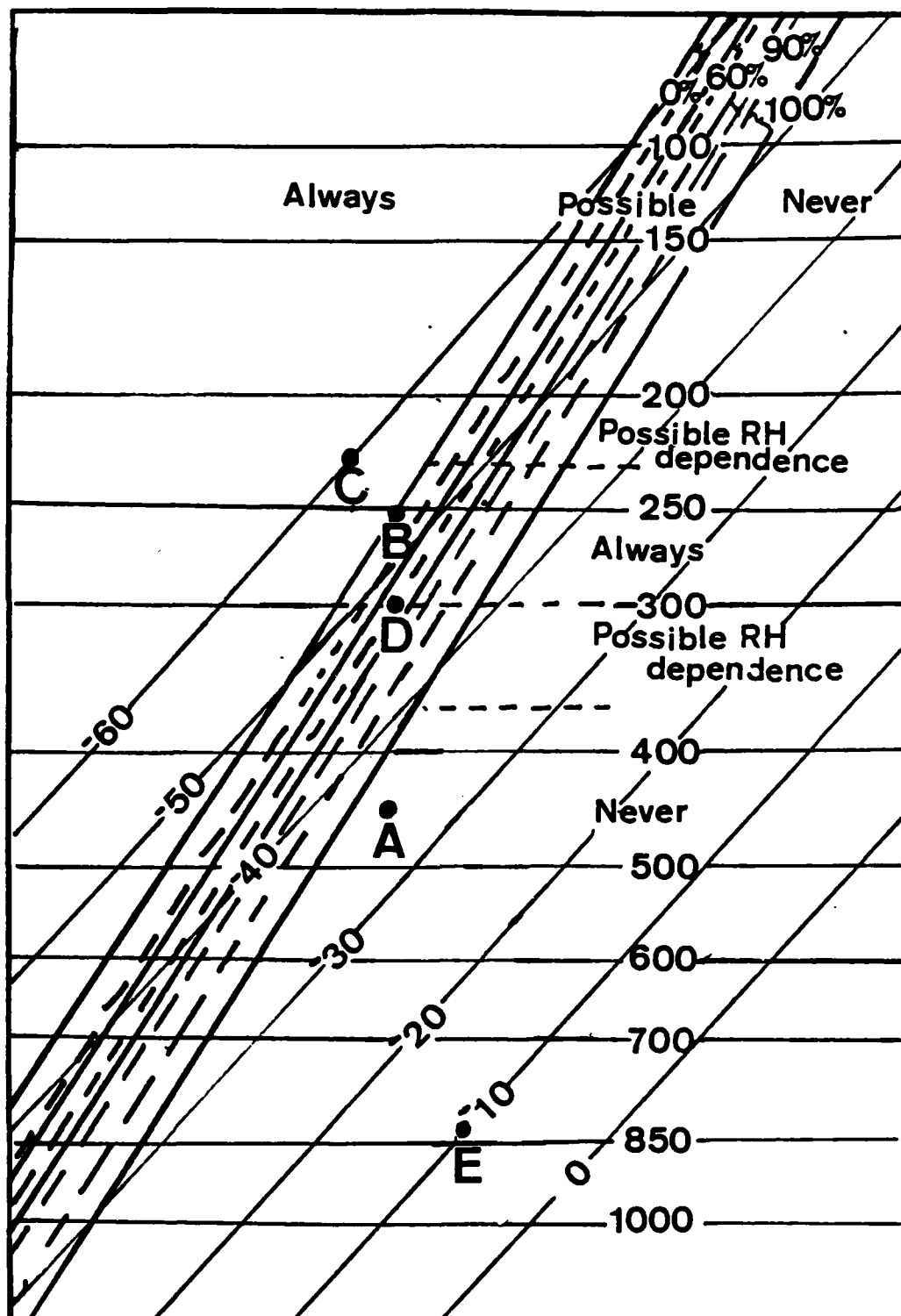
Flag 02 set
T_d known

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Figure 9

Illustration of contrail decisions: curves taken from the Chief of
Naval Operations (1964).

E. **Program**

Table V Contrail Formation Program.

```
01◆LBL "TRAILS"      51 GTO 11           101 STO 02           151 XROM 28,33       201 TONE 7
02 CF 01             52 "DO YOU KNOW"     102 FS? 01           152 X=0?             202 "TD=? C"
03 CF 02             53 AVIEW             103 GTO 12           153 GTO A            203 FS? 21
04 "CHANGE FLAGS?"   54 PSE               104 "ARE THERE"      154 FS? 01           204 PRA
05 PROMPT            55 "DEWPOINT, TD?"   105 AVIEW            155 GTO 14           205 FS? 21
06◆LBL 10            56 AVIEW             106 PSE              156 "FROM MOIST"     206 PRX
07 TONE 1            57 PSE               107 "CIRRUS AT"      157 AVIEW            207 XROM 28,33
08 "P=? MB"          58 "YES  E"          108 AVIEW            158 PSE              208 273
09 FS? 21            59 AVIEW             109 PSE              159 "REGION"         209 +
10 PRA               60 PSE               110 "THIS LEVEL?"    160 AVIEW            210 XEQ "ES"
11 PROMPT            61 "NO=ZERO"         111 AVIEW            161 PSE              211 RCL 02
12 FS? 21            62 AVIEW             112 PSE              162 "= ONE"          212 /
13 PRX               63 PSE               113 "YES=ONE"       163 AVIEW            213 100
14 STO 00            64◆LBL 11            114 AVIEW            164 PSE              214 *
15 LN                65 "KNOW TD?"        115 PSE              165 "FROM DRY"       215 STO 02
16 STO 01            66 FS? 21            116 "NO=ZERO"        166 AVIEW            216 RTN
17 TONE 2            67 PRA               117 AVIEW            167 PSE              217◆LBL "ES"
18 "T=? C"           68 XROM 28,21        118 PSE              168 "= ZERO"         218 1/X
19 FS? 21            69 XROM 28,33        119◆LBL 12           169 AVIEW            219 CHS
20 PRA               70 CHS               120 "CIRRUS?"        170 PSE              220 273
21 PROMPT            71 !                 121 FS? 21           171◆LBL 14           221 1/X
22 FS? 21            72 X=Y?              122 PRA              172 "MST OR DRY?"    222 +
23 PRX               73 GTO 01            123 FS? 21           173 FS? 21           223 2500
24 STO 04            74 0                 124 XROM 28,33       174 PRA              224 *
25 FC? 02            75 STO 02            125 PRX              175 XROM 28,33       225 0.461
26 GTO 03            76 XEQ "TC"          126 X=Y?             176 5                226 /
27◆LBL 01            77 RCL 04            127 GTO A            177 PRX              227 E↑X
28 XEQ "RH"          78 RCL 03            128 XROM 28,33       178 *                228 6
29 XEQ "TC"          79 X>Y?              129 40               179 GTO 39           229 *
30◆LBL 02            80 GTO C             130 STO 02           180 RCL 01           230 RTN
31 RCL 04            81 100               131 FS? 01           181 X<0?             231◆LBL "TC"
32 RCL 03            82 STO 02            132 GTO 13           182◆LBL A            232 -90.4994
33 X>Y?              83 XEQ "TC"          133 "DO YOU"         183 XEQ "TC"         233 STO 03
34 GTO C             84 RCL 03            134 AVIEW            184 RCL 03           234 .5587
35◆LBL D             85 RCL 04            135 PSE              185 RCL 04           235 RCL 01
36 "NO CONTRAILS"    86 X>Y?              136 "KNOW FLOW?"     186 -                236 *
37 TONE 5            87 GTO D             137 AVIEW            187 ABS              237 3.4232
38 AVIEW             88 0                 138 PSE              188 2                238 +
39 ADV               89 STO 02            139 "YES=ONE"       189 X<=Y?            239 RCL 01
40 STOP              90 RCL 00            140 AVIEW            190 GTO 02           240 *
41 GTO 10            91 225               141 PSE              191 "PROBABLY"       241 ST+ 03
42◆LBL C             92 X>Y?              142 "NO=ZERO"        192 AVIEW            242 .0012
43 "CONTRAILS"       93 GTO A             143 AVIEW            193 PSE              243 RCL 02
44 TONE 8            94 40                144 PSE              194 GTO 02           244 *
45 AVIEW             95 STO 02            145◆LBL 13           195◆LBL "RH"         245 -.0372
46 ADV               96 300               146 "KNOW FLOW?"     196 RCL 04           246 +
47 STOP              97 RCL 00            147 FS? 21           197 273              247 RCL 02
48 GTO 10            98 X>Y?              148 PRA              198 +                248 *
49◆LBL 03            99 GTO A             149 FS? 21           199 XEQ "ES"         249 ST+ 03
50 FS? 01            100 60               150 PRX              200 STO 02           250 RTN
                                                                                    251 .END.
```

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V. Determination of Lifting Condensation Level

A. Objective

Given a surface temperature, surface pressure and specific humidity, this program calculates the lifting condensation level.

B. Principles

The lifting condensation level (LCL) is the level to which a parcel of air can be lifted dry adiabatically before it becomes saturated. During the lifting process, the potential temperature of the air parcel and the saturation mixing ratio remain constant. The actual mixing ratio decreases and eventually equals the saturation mixing ratio. The lifting condensation level is obtained when the actual vapor pressure equals the saturation vapor pressure ($e = e_s$). Integrating the Clausius-Clapeyron equation from 273 K to air temperature (T)

$$\int_{273}^{T} \frac{de_s}{e_s} = \int_{273}^{T} \frac{L}{R_w} \frac{dT}{T^2}$$

where e_s is the saturation vapor pressure; L is the latent heat of condensation (2.5×10^6 J/kg); R_w is the gas constant for water vapor (462 J/kg °K); and T is the temperature (°K), results in the following expression for the saturation vapor pressure:

$$e_s = 6.11 \exp \left(\frac{L}{R_w} \left(\frac{1}{273} - \frac{1}{T} \right) \right).$$

Combining the hydrostatic equation and the ideal gas law and expressing the temperature as $T_0 - \gamma z$ results in the following expression relating pressure (P) to height (z):

$$P = P_0 \frac{(T_0 - z)^{\frac{g}{R\gamma}}}{T_0}$$

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where γ is the dry adiabatic lapse rate, T_0 is the standard atmospheric temperature, w is the specific humidity and P_0 is the standard atmospheric pressure. ($w = .622 \, (e/P) ==> P = .622 \, e/w$)

An expression for the actual vapor pressure (e) is obtained by using the definition of specific humidity and substituting the above expression in for P. The lifting condensation level is obtained when the following two equations are equal to each other:

$$e = \frac{wP_0}{.622} \frac{(T_0 - \gamma z)^{\frac{g}{R}\gamma}}{T_0}$$

$$e_s = 6.11 \exp \left[\frac{L}{R_w} \left(\frac{1}{273} - \frac{1}{T_0 - \gamma z} \right) \right]$$

After a series of substitutions, using Taylor series expansion of $\ln x \approx x - 1$ and several algebraic manipulations, the following equation is derived giving the lifting condensation level:

$$z_{LCL} = T_0 \, (102.041 - 14.6429 \, (23.3058 - \ln(\frac{wP_0}{3.80042}) - [\ln(\frac{wP_0}{3.80042})$$

$$- 23.3058^2 - \frac{75418.2}{T_0} \,]^{\frac{1}{2}} \,))$$

Only surface data values of temperature (T_0), pressure (P_0) and specific humidity (w) are required to find the LCL.

C.   User's Guide

1)   Turn on calculator and set printer to the NOR mode.

2)   XEQ LCL

3)   Prompt reads, SFC TEMP °C?

4)   Type in a surface temperature.

5)   Press R/S to enter the temperature.

6)   Prompt is SFC PRES MB?

7)   Enter a surface pressure.

8)   R/S

9)   Prompt reads, SP HUMID G/G?

10) Enter a specific humidity value.

11) R/S

     The lifting condensation level will appear with its value in meters. If
     the LCL occurs at the surface, the word SURFACE will be displayed.

D.   Examples

     Examples A, B and C in Table VI illustrate the use of the program "LCL"
in   estimating the lifting condensation level from a surface temperature,
pressure and specific humidity.   In example A, a surface temperature of 9°C,
a surface pressure of 1010 mb, and a specific humidity of .006 g/g are entered
in the "LCL" program.   The data result in a lifting condensation level of
318.9m   which is verified by a thermodynamic diagram. (See Figure 10.) In
example B, the lifting condensation level occurs at the surface and in example
C, the LCL is at 637.4 m.

Table VI
Examples of the Lifting Condensation Level Program.

A

```
SFC TEMP C?
          9.0000
SFC PRES MB?
      1,010.0000
SP HUMID G/G?
          .0060
LCL, M,=318.8959
```

B

```
SFC TEMP C?
          .5000
SFC PRES MB?
      1,000.0000
SP HUMID G/G?
          .0040
SURFACE
```

C

```
SFC TEMP C?
          6.0000
SFC PRES MB?
      1,020.0000
SP HUMID G/G?
          .0040
LCL, M,=637.3732
```
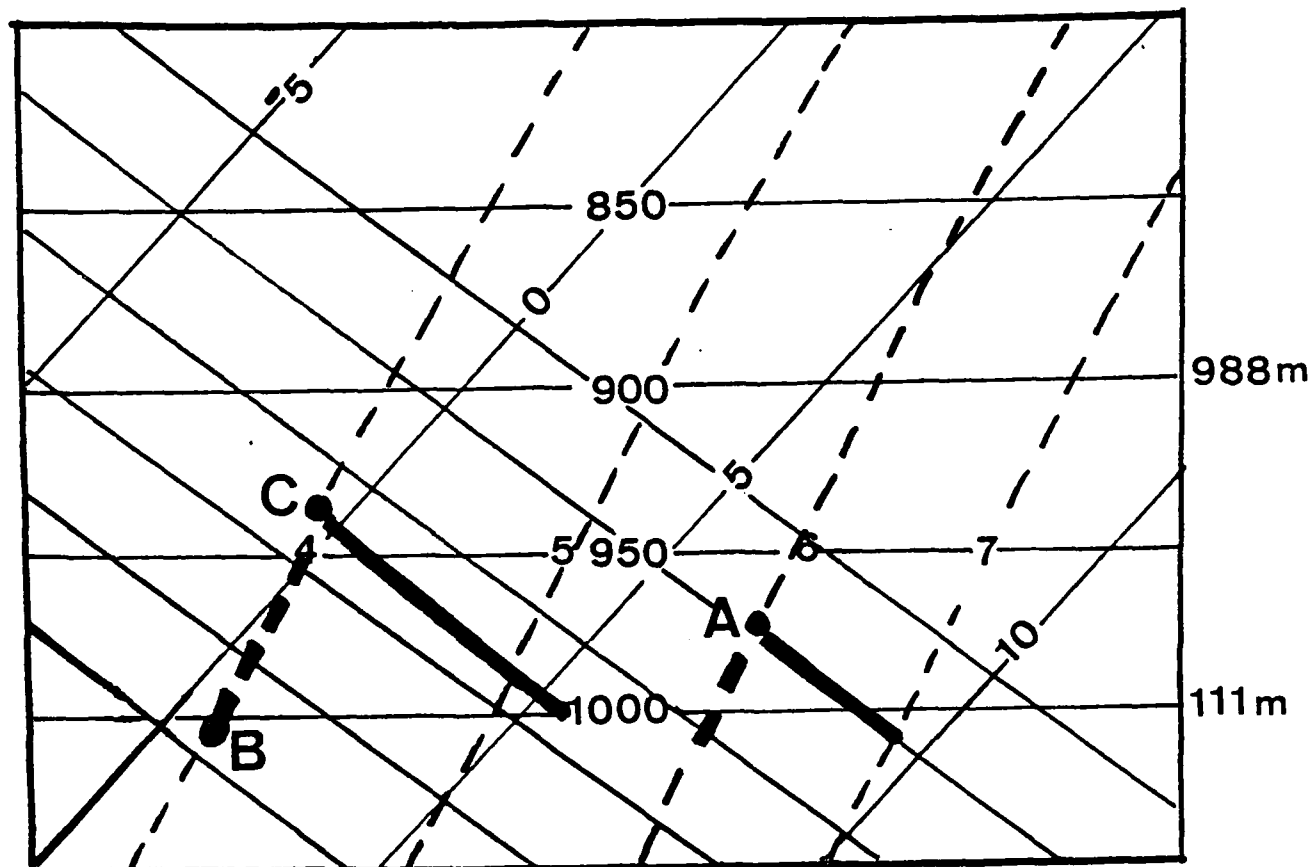
Figure 10

Lifting condensation levels determined by surface temperature, pressure and specific humidity.

E. Program

Table VII
Lifting Condensation Level Program.

```
01•LBL "LCL"        29 STO 26
02 23.3058          30 CHS
03 STO 25           31 RCL 24
04 "SFC TEMP C?"    32 CHS
05 PROMPT           33 +
06 273.15           34 RCL 25
07 +                35 +
08 STO 21           36 14.6429
09 "SFC PRES MB?"   37 *
10 PROMPT           38 102.041
11 STO 22           39 X<>Y
12 "SP HUMID G/G?"  40 -
13 PROMPT           41 RCL 21
14 STO 23           42 *
15 RCL 22           43 STO 30
16 *                44 0
17 3.80042          45 X<>Y
18 /                46 X<=Y?
19 LN               47 GTO "SFC"
20 STO 24           48 "LCL, M,="
21 RCL 25           49 ARCL 30
22 -                50 AVIEW
23 X+2              51 GTO "END"
24 75418.2          52•LBL "SFC"
25 RCL 21           53 "SURFACE"
26 /                54 AVIEW
27 -                55•LBL "END"
28 SQRT             56 .END.
```

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Acknowledgements

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